ISSN 1846-6168
UDK 539.5

UTJECAJ TVRDOĆE PODLOGE NA OTPORNOST ABRAZIJSKOM TROŠENJU TRIBOLOŠKIH PREVLAKA

INFLUENCE OF SUBSTRATE HARDNESS ON ABRASIVE WEAR RESISTANCE OF TRIBOLOGICAL COATINGS

Goran Heffer, Robert Poretti, Ivan Plaščak

Prethodno priopćenje

Sažetak: *U radu je prikazana usporedna analiza svojstava triboloških prevlaka dobivenih toplinsko-kemijskim postupcima - klasično vanadirana prevlaka i vanadirana prevlaka s prethodno naugljičenim supstratom, koje su primjenjene za zaštitu od abrazijskog trošenja. Uspoređivana su svojstva tvrdoće prevlake, tvrdoće supstrata ispod prevlake i otpornosti prevlake abrazijskom trošenju. Usporedna analiza potvrdila je opravdanost uvođenja naugljičenja supstrata prije postupka vanadiranja zbog povećanja otpornosti abrazijskom trošenju.*

Ključne riječi: *tribološka prevlaka, toplinsko-kemijski postupak, vanadiranje, naugljičenje, supstrat, abrazijsko trošenje*

Preliminary communication

Abstract: *The paper gives comparative analysis of properties of tribological coatings obtained by thermo chemical processes - classical vanadizing coating and vanadizing coating with prior carburization of the substrate, used as protection against abrasive wear. Properties of coating hardness, substrate hardness underneath the coating and abrasive wear resistance of the coating are compared. The comparative analysis proved justification for introduction of carburization of the substrate prior to vanadizing process because of abrasive wear resistance increase.*

Key words: *tribological coating, thermo-chemical process, vanadizing, carburization, substrate, abrasive wear*

1. INTRODUCTION

One of measures undertaken to increase wear resistance is a selection of material which is resistant to specific form of wear [1, 2].

Different sorts of coatings play an essential role in such application, i.e. surface layers protecting the substrate (base material) of certain structure. In application of such coatings, different thermo chemical processes are being applied, such as: carburizing, nitriding, carbonitriding, boronizing, combined processes, etc.

One of significant processes is also vanadizing coating (V-coating) process. The wear resistance of V-coatings depends on surface hardness but also on hardness of substrate under the coating [3, 4]. That is experimental confirmed in this work.

2. MATERIALS AND METHODS

Vanadium carbide (VC) coating technology is thermal and chemical process of application of strong carbide-producing element vanadium (V) by thermal diffusion technology, producing in reaction with carbide contained in the substrate (steel), for surface layer of vanadium carbide.

This process is carried out on temperatures 900 to 1100 °C for several hours, during which process the parts are surrounded by high vanadium content ambient in the form of granulate or immersed in a salt bath. After that comes process of quenching so as to obtain additional hardening of the substrate under the thin and hard surface layer.

V-coating hardness depends upon temperature and duration of thermal diffusion process and the chemical composition of the substrate, where carbon content participating in formation of the carbide layer represents an essential factor [5].

2.1. Coating obtained by classical vanadium coating process

Experimental samples with dimension 12×25×75 mm were made out of carbon steel DIN C45. The chemical composition of C45 is shown in table 1 [6].

V-coating process was carried out on Chair for Thermal Treatment and Engineering of Surfaces of the Faculty for Mechanical Engineering and Naval Architecture in Zagreb.

Table 1 Chemical composition of C45 (%)

C	Si	Mn	Cr	Ni
0.46	max 0.40	0.65	max 0.40	max 0.40
Mo	**W**	**V**	**Others**	
max 0.10	-	-	(Cr+Mo+Ni) = max 0.63	

Vanadizing was conducted in salt bath on 950 ºC for 4 hours. After vanadizing, samples were quenched in water. Uniform thickness of V-coating with clear boundaries between V-layer and the substrate can be observed. Thickness of the obtained vanadium layer is approximately 5 µm.

Fig. 1 shows the coating microstructure.

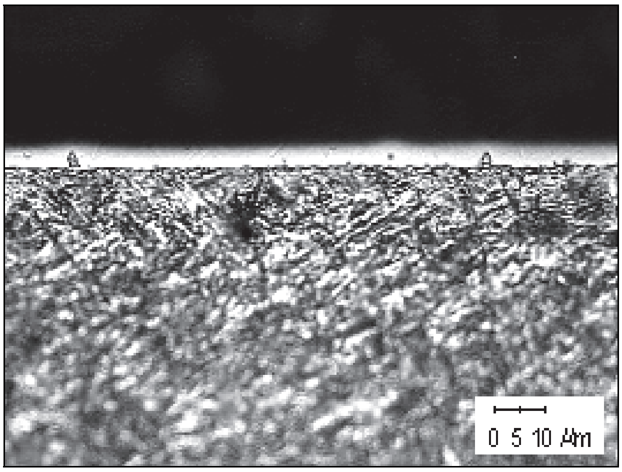

Figure 1 Microstructure of classical V-coated specimen

2.2. Coating obtained by V-coating process with prior carburization of the substrate

As already stated, V-coating process creates a layer of vanadium carbide on the substrate surface. Material lying under this layer partially loses carbon content (decarburization), due to its diffusion from interior towards surface and chemical reaction with vanadium. Therefore, immediately under the vanadium carbide layer there is carbide concentration lower then in the core of the treated material. Since the quenching comes after V-coating, lower carbide concentration under carbide layer leads to softer structure in this area. Such plunge in hardness value of the base material can be dangerous for the thin surface layer, because it does not provide it with sufficiently hard base in operational conditions, which are abundant with high stresses, leading to breakage of the surface layer. Carburization, i.e. carbon diffusion in the material surface prior to V-coating results in structure more abundant in carbon content. Since carbon content directly influences the thickness of the vanadium layer, carburization provides possibility for thicker vanadium layer and reduction of lack of carbon in area underneath the coating. This means that such process provides not only harder structure by additional quenching, but also enables V-coating of steel with lesser carbon content [7]. Experimental samples were also V-coated in salt bath at the temperature of 950 ºC for 4 hours, after carburization in atmosphere rich with carbon. After V-coating process, they were quenched in water. Thickness of the obtained layer was approximately 7.5 µm. Fig. 2 shows microstructure of the obtained coating.

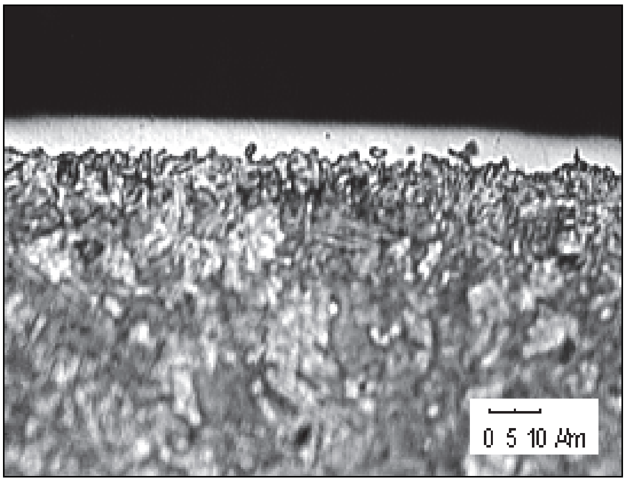

Figure 2 Microstructure of V-coated specimen with prior carburization

2.3. Methods for comparison of coatings

Three properties of the obtained coatings were compared: coating hardness, hardness of substrate underneath the coating and resistance of coating to abrasive wear.

Method for comparison of coating hardness Coating hardness was measured by Vickers method $HV_{0.03}$ on several points on the surface and shown as average hardness values.

Method for comparison of substrate hardness. Substrate hardness of classically V-coating and V-coating with prior carburization was measured under surface carbide layer in depth, using Vickers method $HV_{0.05}$.

Methods for comparison of abrasive wear resistance. To determine and compare abrasive wear resistance properties, sample mass loss values (Δm) were measured for both coating layers, after carried out of two abrasion wear tests:

- Standard wear test "dry sand/rubber wheel";
- Abrasion by moving through the mass of free abrasive particles.

2.3.1. Standard wear test "dry sand/rubber wheel"

The wear test was carried out in Laboratory for Tribology of the Faculty for Mechanical Engineering and Naval Architecture in Zagreb. Testing was conducted on standard device, according to ASTM G65-94 [8], by modified procedure of standard D-test variant.

The testing parameters are shown in Table 2.

Table 2 Testing parameters

Force on specimen, N	Number of rubber wheel revolutions, n	Relative wear path, m
45	1000	718

Sketch of wear test device is shown on Fig. 3.

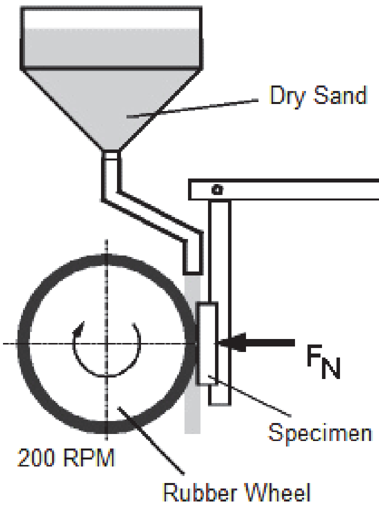

Figure 3 Sketch of device for "dry sand/rubber wheel" method

Standard D-test variant was modified with regard to reduction of number of revolutions of the rubber wheel from standard 6000 to 1000 revolutions, due to very small carbide layer thickness and danger of penetration of the coating during experiment.

The volume loss (ΔV) was calculated on the basis of measured mass losses and the data about vanadium layer density of 5380 kg/m^3 [9]. Results of abrasive wear resistance are shown in Table 4 and Fig. 5.

2.3.2. Abrasion by moving through the mass of free abrasive particles

Abrasion wear test was carried out in Department for Agricultural Technics of the Faculty of Agriculture in Osijek [10]. The tribometer for testing was also designed on Faculty of Agriculture in Osijek, according [11], sketched in Figure 4.

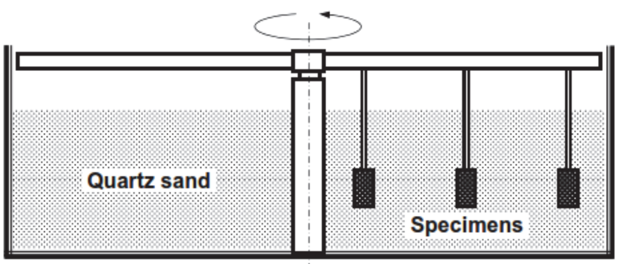

Figure 4 Sketch of designed tribometer

Abrasive particles in the test were rounded quartz sand Ottawa AFS 50/70, used in the standard wear test "dry sand/rubber wheel", according to ASTM G65-94.

The parameters of wear test were:

- Movement velocity of the specimen in the mass of abrasive particles – 1 m/s, 2 m/s, 3 m/s;
- Impact angle of abrasive particles with the surface of the specimen – 45°;
- Relative wear path or path that exceeds the specimen which moves through mass of abrasive particles – 50.000 m (50 km).

3. RESULTS AND DISCUSSION

3.1. Comparison of coating hardness

Average measured values of coating hardness are:

- Hardness of classical V-coated surface amounts to 2100 $HV_{0.03}$;
- Hardness of V-coated surface with prior carburization amounts to 2150 $HV_{0.03}$.

3.2. Comparison of substrate hardness

Measured values of substrate hardness of classically V-coating and V-coating with prior carburization are shown in Table 3.

Table 3 Measured substrate hardness

Depth (mm)	$HV_{0.05}$ classical	$HV_{0.05}$ prior carburization
0,02	285	373
0,05	288	367
0,10	293	376
0,15	299	381
0,20	310	402
0,25	344	396
0,30	340	412
0,35	388	399
0,40	399	397
0,50	399	418
0,60	413	411
0,70	410	409
0,80	412	411

Graphic representation of measured values, which is shown in Fig. 5, shows significant differences in depth hardness values.

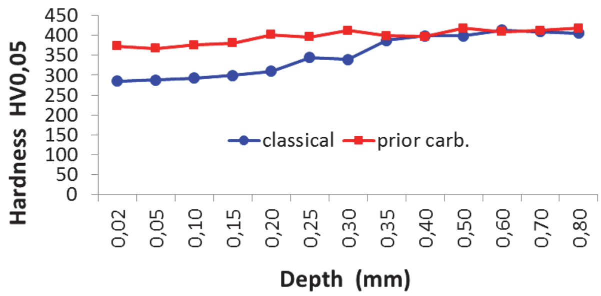

Figure 5 Substrate hardness

In classically V-coated specimens there is a drop of hardness value due to decarburization process undertaken during V-coating process, while the specimens obtained by coating with prior carburization have approximately same hardness values like those in the quenched part of the substrate, due to lack of decarburization.

3.3. Comparison of abrasive wear resistance

Standard wear test "dry sand/rubber wheel". The measured mass and volume losses of V-coatings are shown in Table 4.

Table 4 Abrasive wear resistance

Classical V-coating		With prior carburization	
Δm, g	ΔV, mm^3	Δm, g	ΔV, mm^3
0,003066	0,570	0,002166	0,403

The graph of test results is shown in Figure 6.

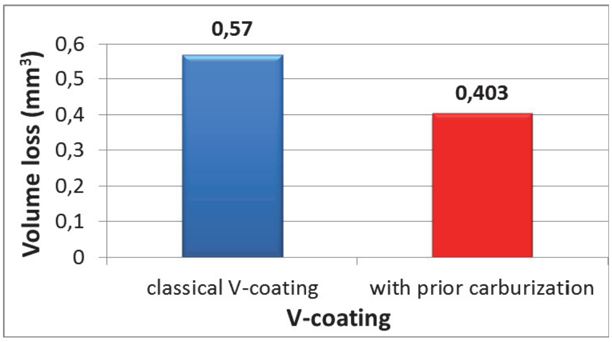

Figure 6 Comparison of abrasive wear resistance of coating

Abrasion test by moving through the mass of abrasive particles. The measured mass and volume losses are shown in Table 5.

Table 5 Measured mass and volume losses

Coating	Loss by wear	Velocity, m/s		
		1,0	2,0	3,0
classical	Δm, g	0,0027	0,0035	0,0077
	ΔV, mm^3	0,502	0,651	1,431
prior carbur.	Δm, g	0,0025	0,0029	0,0060
	ΔV, mm^3	0,465	0,539	1,115

The graph of test results is shown in Figure 7.

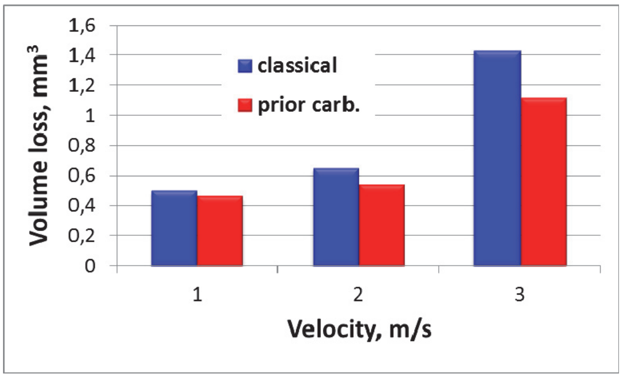

Figure 7 Comparison of abrasive wear resistance of coating

4. CONCLUSION

The conducted testing demonstrates that coating obtained by V-coating process with prior carburization of substrate showed slight increase of hardness value, but also significantly higher abrasive wear resistance than coatings obtained by classical V-coating process. Reason for that lies in retained hardness of the substrate which is immediately under carbide layer.

Therefore the testing also confirms appropriateness of application of prior carburization to V-coating process for increasing of abrasive wear resistance.

5. REFERENCES

[1] Ivušić, V.: Tribologija, Hrvatsko društvo za materijale i tribologiju, Zagreb, 1998.
[2] HDMT: Inženjerstvo površina, bilten HDMT br. 1/93, Zagreb, 1993.
[3] Schauperl, Z.: Utjecaj tvrdoće podloge na trajnost tankih tvrdih prevlaka, Ph.D. Thesis, FSB Zagreb, 2000.
[4] Heffer, G.: Trošenje triboloških prevlaka pri gibanju u masi slobodnih abrazijskih čestica, Ph.D. Th., FSB Zagreb, 2002.
[5] Matijević, B.: Kinetika difuzijskog stvaranja karbidnih slojeva, Ph.D. Thesis, FSB Zagreb, 1997.
[6] "Metal Ravne", Slovenia, Structural Steel Data Sheets, 2002.
[7] Stupnišek, M.; Matijević, B.: Oplemenjivanje alata tvrdim karbidnim slojem, Proceedings of the Symposim "Suvremene tehnologije toplinske obradbe čelika", pp. 41-50, FSB Zagreb, 1998.
[8] ASTM: Standard Test Method for Measuring Abrasion Using the Dry Sand/Rubber Whell Apparatus, ASTM, 1994.
[9] Grilec, K.: Otpornost na abrazijsko trošenje triboloških prevlaka, M.Sc. Thes., FSB Zagreb, 1998
[10] Poretti, R.: Primjena tvrdih slojeva u zaštiti od trošenja radnih dijelova poljoprivredne mehanizacije, diplomski rad, Poljoprivredni fakultet Osijek, 2008.
[11] Vinogradov, V.N.; Sorokin, G.M.; Kolokolnikov, M.G.: Abrazivnoe iznašivanie, Mašinostroenie, Moskva, 1990.
[12] Hogmark, S.; Hedenquist, P.: Tribological characterization of thin, hard coatings, Wear 179, 147-154, 1994.

Author contacts:

Associate Professor Goran Heffer, Ph.D.
Faculty of Agriculture in Osijek, Department for Agricultural Technics
Kralja Petra Svačića 1d, 31000 Osijek
E-mail: goran.heffer@pfos.hr

Robert Poretti, B.Sc. ing.
Former Student to Faculty of Agriculture in Osijek
J.J. Strossmayera 158, 31000 Osijek

Assistant Professor Ivan Plaščak, Ph.D.
Faculty of Agriculture in Osijek, Department for Agricultural Technics
Kralja Petra Svačića 1d, 31000 Osijek
E-mail: ivan.plascak@pfos.hr